Evidence for a planetary companion around a nearby young star

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ABSTRACT

We report evidence for a planetary companion around the nearby young star HD 70573. The star is a G type dwarf located at a distance of 46 pc with age estimation between 20 and 300 Myrs. We carried out spectroscopic observations of this star with FEROS at the 2.2 m MPG/ESO telescope at La Silla. Our spectroscopic analysis yields a spectral type of G1-1.5V and an age of about 100 Myrs. Variations in stellar radial velocity of HD 70573 have been monitored since December 2003 until January 2007. The velocity accuracy of FEROS within this period is about 10 m/s. HD 70573 shows a radial velocity variation with a period of 852($\pm$12) days and a semi-amplitude of 149($\pm$6) m/s. The period of this variation is significantly longer than its rotational period, which is 3.3 days. Based on the analysis of the Ca II K emission line, Hα and $T_{\rm eff}$ variation as stellar activity indicators as well as the lack of a correlation between the bisector velocity span and the radial velocity, we can exclude the rotational modulation and non-radial pulsations as the source of the long-period radial velocity variation. Thus, the presence of a low-mass companion around the star provides the best explanation for the observed radial velocity variation. Assuming a primary mass $m_1 = 1.0 \pm 0.1$ $\mathrm{M_{Sun}}$ for the host star, we calculated a minimum mass of the companion $m_2 \sin i$ of 6.1 $\mathrm{M_{Jup}}$, which lies in the planetary mass regime, and an orbital semi-major axis of 1.76 AU. The orbit of the planet has an eccentricity of $e = 0.4$. The planet discovery around the young star HD 70573 gives an important input for the study of debris disks around young stars and their relation to the presence of planets.

Subject headings: stars: general — stars: individual: HD 70573 — stars: planetary systems — techniques: radial velocities

1. Introduction

Precise radial velocity (RV) measurements are a well established technique in detecting extrasolar planets around non-active stars, like solar-type stars with similar masses and ages to our Sun (see e.g., Butler et al. 2006). This technique has been also applied in the late 1980's for planet searches around cool evolved stars (Cochran & Hatzes 1989). However, the number of extrasolar planets around such non solar-type stars is still very small compared to planets around solar-like stars. The situation for young stars is similar, where practically no convincing case is known so far. Planet detections around young and active stars are indeed much more difficult than those around evolved and quiet solar-like stars.

Many young stars possess high levels of stellar activity and are also known as fast rotators. Spectroscopically this is indicated by strong line broadening and the presence of emission line features, in particular Hα (λ6536 Å), Ca II H (λ3967 Å) and K (λ3934 Å). Within the same spectral class the stellar activity of young stars is considerably higher than for older stars. The rotational velocity of F-, G- and K-type young stars can be as high as a few hundreds km/s which can be observed by strong line broadening. This makes precise RV measurements very difficult. Intrinsic stellar activity, like non-radial pulsations and rotational modulation, manifests itself in RV variation. In order to distinguish the sources of RV variation in active stars, the stellar spectra have to be investigated carefully, for instance, via the bisector analysis (e.g., Hatzes 1996) and stellar activity indicators, like Ca II H & K emission lines and variation in Hα line, to avoid a misinterpretation of the observed RV variation. This kind of analysis is indispensable for planet searches around active young stars.

The search for young planetary systems by the RV technique is indeed limited to young stars which do not show a high activity level. Such a high stellar activity affects the accuracy of the RV method, like in stars with high rotational velocity ($v \sin i > 20\,\mathrm{km/s}$). Nevertheless, in comparison to other young planet search methods, like the direct imaging techniques, the RV method is more sensitive to planetary companions with closer orbits, i.e., less than 10 AU to the parent stars. A further advantage compared to direct imaging is, that the RV method is not strongly limited by distance. It can be applied to planet searches in nearby young moving groups (30–70 pc) and star-forming regions at $>100\,\mathrm{pc}$ (e.g., the Taurus-Auriga region at 140 pc), for which direct imaging methods are not possible.

This work reports the discovery of a planetary companion around the nearby young star HD 70573. Our RV measurements of HD 70573 show a periodic variation on a time scale which is much longer than the stellar rotational period. This excludes rotational modulation as the source of RV variation. We will show that the bisector technique allows us to distinguish intrinsic stellar activity (non-radial pulsations or stellar rotational modulation

due to starspots) from variability due to companions. By measuring the bisector velocity spans we detected rotational modulation in other young stars of our sample (Setiawan et al., in preparation). The planet detection around HD 70573 is concluded by the lack of the correlation between the observed RVs and stellar activity indicators (Sect. 4).

2. HD 70573: A nearby young star

HD 70573 was identified by Jeffries (1995) as a Lithium rich star. He predicted an age of this star to be substantially younger than 300 Myrs. In a study of young stellar kinematic groups by Montes et al. (2001a), HD 70573 has been classified as a member of the Local Association (Pleiades moving group) with an age range between 20 and 150 Myrs. Later, Lopéz-Santiago et al. (2006) classified HD 70573 as a member of the Hercules-Lyra association, a group of stars comoving in space towards the constellation of Hercules. This moving group has an estimated age of ∼200 Myrs. By comparing the equivalent width of Li λ6708 Å versus the spectral type diagram (Fig. 2 in Montes et al. 2001b), we derived an age within the Pleiades age regime (78–125 Myrs).

The stellar parameters of HD 70573 are compiled in Table 1. We measured the equivalent widths (EW) of neutral and ionized lines as described in Gray (1992). By comparing our EW measurements with the EWs of standard stars adopted from Cayrel de Strobel (2001) and by using the relation between EWs and temperature we derive the spectral type of G1-1.5V for HD 70573. The stellar parameters $T_{\rm eff}$, [Fe/H], $\log g$ have been calculated by using the TGV model (Takeda et al. 2002), which computes the stellar parameters from the EW of FeI and Fe II.

The absolute visual magnitude has been calculated from the visual brightness $m_V = 8.70$ mag and the distance $d = 45.7$ pc (Lopéz-Santiago et al. 2006). Henry et al. (2005) has measured photometric variations of HD 70573 and found a period of 3.296 days, which corresponds to the rotational period of the star. We measured the projected rotational velocity $v \sin i$ from the spectral lines by using a cross-correlation method (Benz & Mayor 1981) with the instrumental calibration from Setiawan et al. (2004). Our measured value (see Table 1) is slightly higher than the value published by Henry et al. (1995), who derived $v \sin i = 11$ km/s.

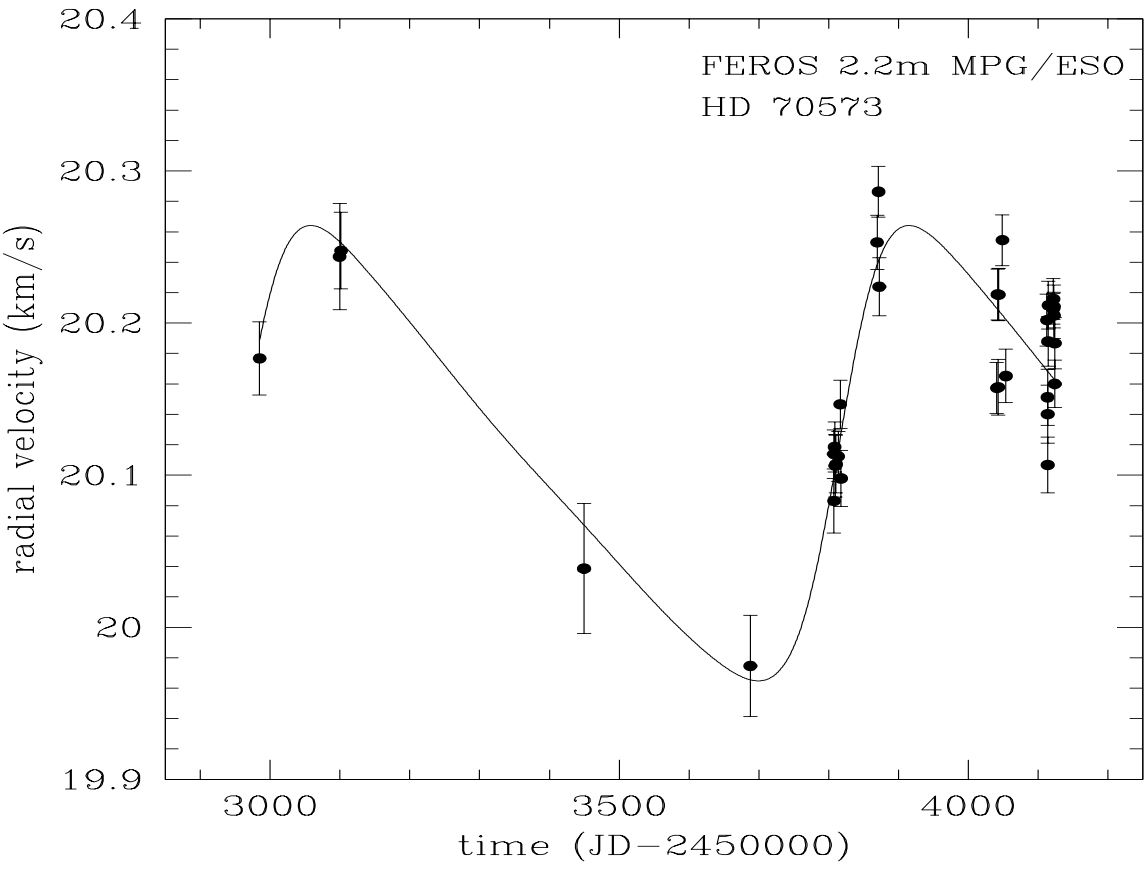

Fig. 1.— RV measurements of HD 70573. We observed a long-period RV variation of 852 days and short-period variation of few days (see text).

3. Observations and results

We are carrying out a RV survey of a sample of young stars with FEROS at the 2.2 m MPG/ESO telescope located at ESO La Silla Observatory, Chile. The spectrograph has a resolution of $R = 48\,000$ and a wavelength coverage of 3600–9200 Å (Kaufer & Pasquini 1998).

The data reduction has been performed by using the online pipeline, which produces 39 orders of one-dimensional spectra. The RVs have been measured with the simultaneous calibration mode of FEROS and a cross-correlation technique (Baranne et al. 1996). During the period of three years we obtained a long-term stability of FEROS that is about 10 m/s.

RV measurements of HD 70573 are shown in Fig. 1. We observed a long-term RV variation with a period of 852±12 days, which is much longer than the period of the photometric

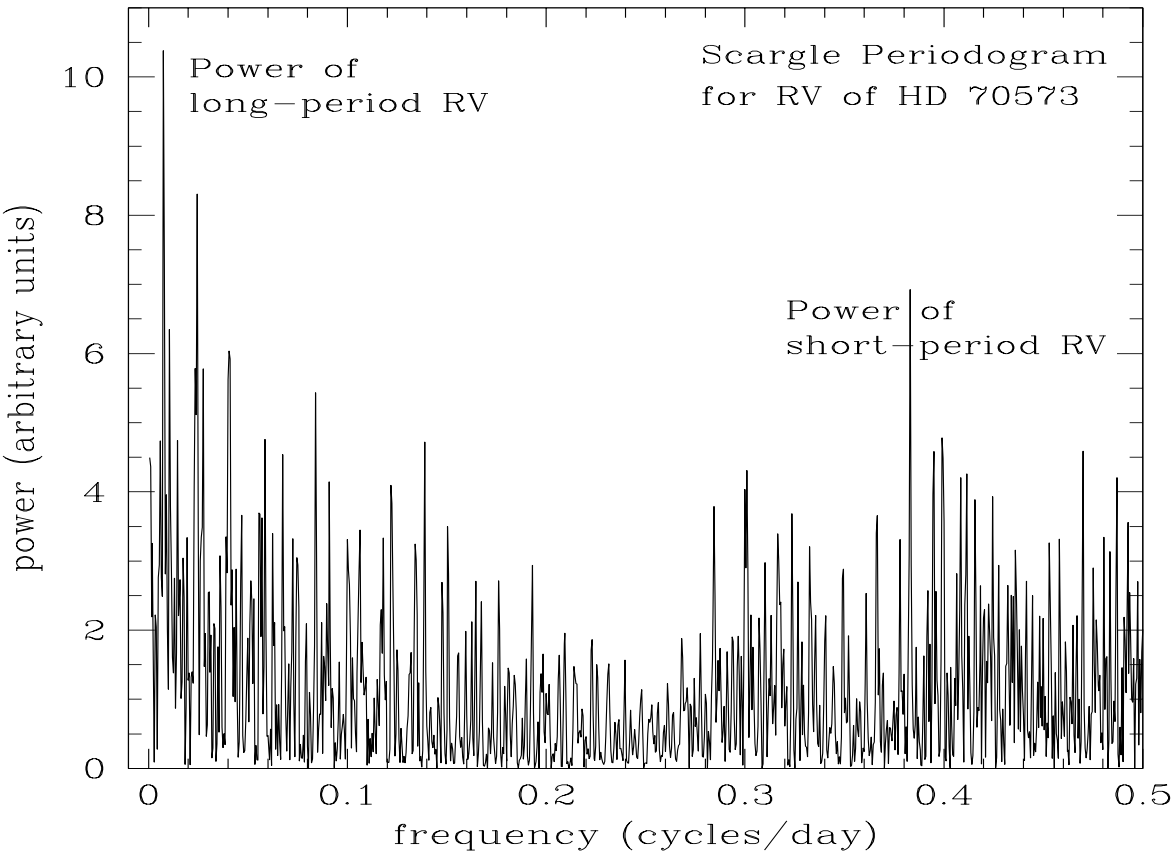

Fig. 2.— Lomb-Scargle Periodogram of the RV variation of HD 70573

variability. The semi-amplitude of the RV variation is 149±16 m/s. A Lomb-Scargle periodogram (Scargle 1982) of the RVs show the highest peak in the power, which corresponds to the long-period RV variation. On a smaller time scale of several days we also detected short-term RV variations. In the Lomb-Scargle periodogram we also found a lower peak in the power, which corresponds to a period of $\sim$ 2.6 days. This is comparable to the period in the photometric variation detected by Henry et al. (1995). The False Alarm Probability (FAP) of the peaks are 1.1×10^{-3} for the long-period RV variation and 3.5×10^{-2} for the short-period one. Additional RV measurements, taken with interval of few hours in several consecutive days, may increase the power in the frequency region that corresponds to the period of $\sim$3 days.

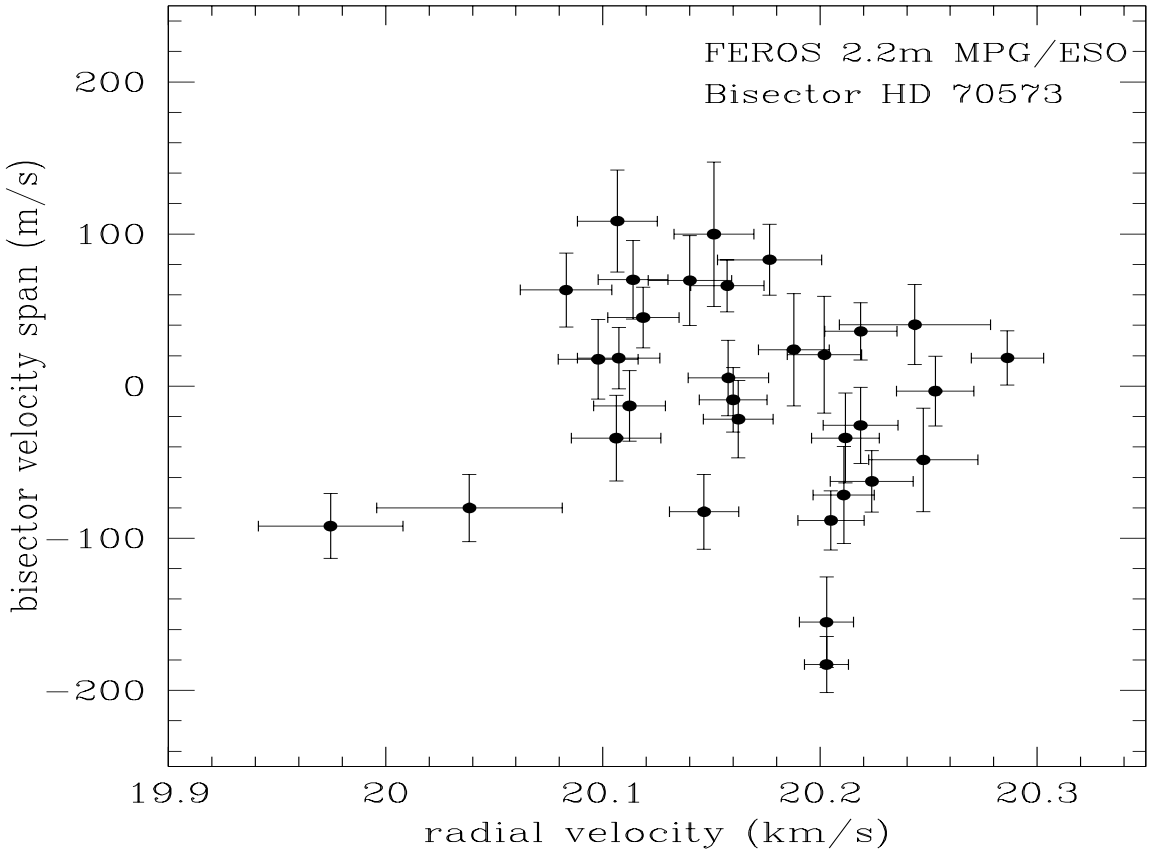

Fig. 3.— Bisector velocity span vs. RV of HD 70573. The figure shows no correlation between both quantities. This favors the presence of a low-mass companion rather than stellar activity as the source of RV variation.

4. Testing the stellar activity

As detected in many surveys, young stars show high stellar activity, characterized by strong X-ray, Hα, Ca II H and K emission. In addition, they are also known as fast rotators. For example, large surveys of young stars in star-forming regions such as NGC 2264 (Lamm et al. 2004) show that the objects are often fast rotators with periods between 0.2 and 15 days. Stellar magnetic activity manifests itself by starspots and granulation, as observed in the Sun. Pulsations have also been observed in young stars (e.g., Marconi et al. 2000).

To measure the stellar activity of HD 70573 we investigated the variation of the Ca II K emission line (λ3934 Å) and Hα. We did not use of the Ca II H (λ3967 Å) to avoid the blend which can be caused by the Hϵ line of the Balmer series. Similar to the method used

by Santos et al. (2000), we computed an activity index by measuring the intensity of the Ca II K relative to the intensities of 2 Å windows located in the blue and red part of the spectra, which are close to the Ca II K region and do not have strong absorption features. Our measurements do not show any long period variation which might be correlated with the RV variation. The relative rms of the S-index variation is 4.5% of the mean value. In addition, we also measured the equivalent width (EW) variation of the Hα line and $T_{\rm eff}$ variation by using the line-ratio technique (e.g., Catalano et al. 2002) to search for the stellar activity. The EW measurements of the Hα line give a value of 961$\pm$45 mÅ. The rms of 45 mÅ corresponds to 4.7% variation in the EW, that is similar to the variation observed in the Ca II K emission line. We observed a short-term $T_{\rm eff}$ variation with a peak-to-peak value of $\sim$220 K and a period of few days, which is close to the stellar rotational period. This result means an approximately 4% variation in $T_{\rm eff}$ (Table 1) and thus in good agreement with other stellar activity indicators. However, we did not find any long-term periodicity. The equivalent width variation of the Hα line also does not show any long period variation.

The stellar activity will leave imprints on the spectral line profile. Another possibility to characterize the stellar activity in the spectra is by using the bisector or the bisector velocity span (Hatzes 1996), which measures the asymmetry of the spectral line profile. Equivalently, the bisector velocity span method can be applied to the cross-correlation function used for the RV computation (Queloz et al. 2001). A correlation between bisector velocity spans and RVs should be expected, if the activity is responsible for the RV variation. In contrast to non-active solar-like stars, the bisector velocity spans of active stars are not constant. The scatter in the velocity spans may provide information about the activity level of the star.

In HD 70573 we found no correlation between the bisector velocity spans and RVs (Fig. 3). Thus, based on the results of our analysis of the Ca II K emission lines, Hα, temperature variation and bisector velocity spans as stellar activity indicators we conclude that the observed long-period RV variation of HD 70573 is most likely due to the presence of a low-mass (substellar) companion.

5. Discussion

We computed an orbital solution for the RV data of HD 70573 by using a standard Keplerian fit with χ^2 minimization. The orbital parameters are listed in Table 2. HD 70573 b is probably the youngest extrasolar planet detected so far with the RV technique (Fig. 4).

Planet discoveries around young stars provide important constraints for theories of planet formation. An example is the migration process of planets occurring in the gas-rich

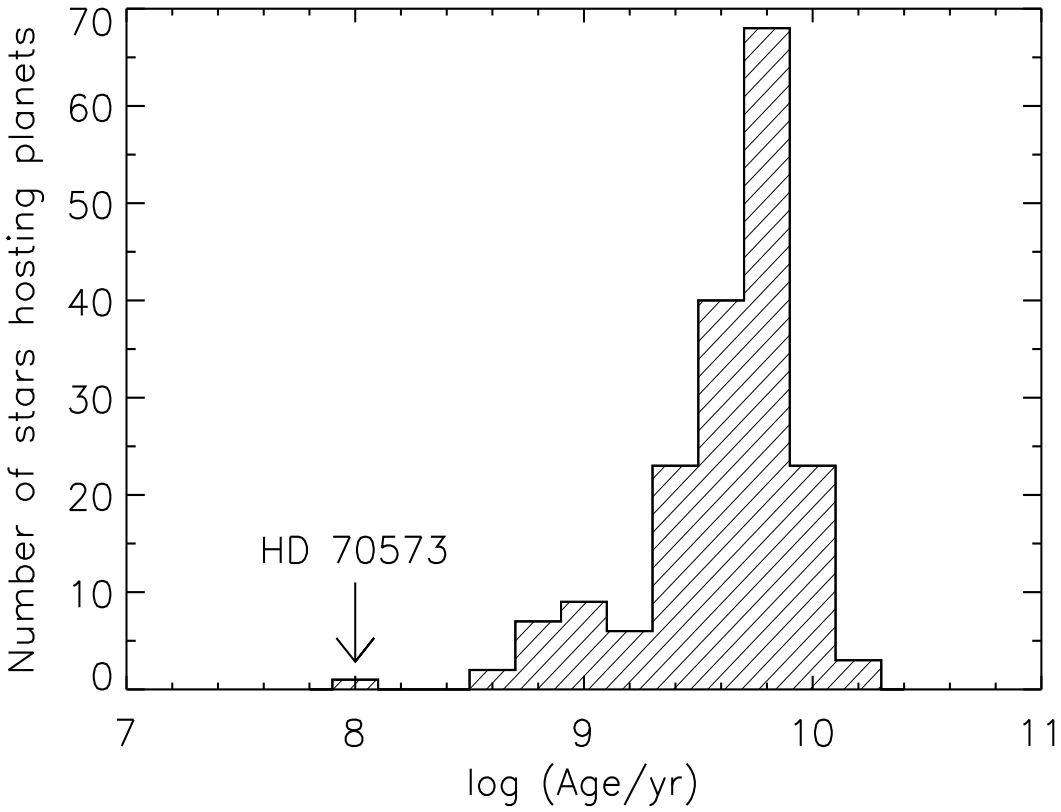

Fig. 4.— A histogram of the ages of exoplanets as of November 2006. HD 70573 b is the youngest planet detected so far by the RV method.

phases of protoplanetary disks. The detection of young planets will also allow us to study the relation between extrasolar planets and the structure of debris disks (Moro-Martín et al. 2006). Since HD 70573 is part of the young star sample of the SPITZER/FEPS legacy program (Meyer et al. 2004), the detection of a planetary companion around this star is of great interest for the study of the relation between debris disks and planets. With a spectral type of G1-1.5V and an age of only 3–6 % of the age of the Sun, the planetary system around HD 70573 could resemble the young Solar system.

More planet discoveries around young stars will certainly improve our understanding of planetary systems in their early evolutionary stages. Since planet searches around young stars via the RV method are restricted to the visual wavelength region and are strongly affected by stellar activity, other detection techniques like, e.g., NIR direct imaging or astrometry, are gaining importance and will most likely soon deliver more discoveries. Astrometric

measurements with a precision level of few tens of μas, for example, will be able to detect the astrometric signal of the planet around HD 70573, which is $\sim$0.23 mas.

Finally, with the detection of a planetary companion around the young star HD 70573 we have shown, that the RV technique is still potentially profitable for the planet search programs.

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Facilities: FEROS, 2.2 m MPG/ESO.

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Table 1: Stellar parameters of HD 70573.

Spectral type	G1-1.5V	
M_V	0.4	mag
distance	45.7	pc
m	1.0 ±0.1	$M_\odot$
$T_{\rm eff}$	5737 ±70	K
$[Fe/H]$	-0.18 ±0.2	$[Fe/H]_\odot$
$\log g$	4.59 ±0.1	
EW(Li)	156 ±20	mÅ
Age	78–125	Myrs
$v \sin i$	14.7 ±1.0	km/s
$P_{\rm rot}$	3.296	days

Table 2: Orbital parameters of HD 70573 b

P	851.8 ± 11.6	days
K_1	148.5 ± 16.5	m/s
e	0.4 ± 0.1	
ω	269.6 ± 14.3	deg
$JD_0 - 2450000$	2106.54 ± 25.72	days
reduced χ^2	1.34	
$O - C$	18.7	m/s
m_1	1.0 ± 0.1	$M_\odot$
$m_2 sini$	6.1 ± 0.4	$M_{\rm Jup}$
a	1.76 ± 0.05	AU